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APPLICATIONS OF THE DOD WORLD GEODETIC SYSTEM - 1972 TO CHARTIN--ETC(U)
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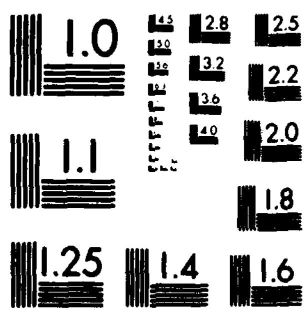
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

DMA has a semi-automated system that is used to evaluate the horizontal datum of maps and charts for geodetic accuracy. Geodetic control descriptions in the DMAHTC library of holdings are used to make this evaluation. The computer system gives geodetic shifts to source maps, surveys, and charts. The chart is compiled from a panel base with the WGS-72 shifts applied. The final color proof of the chart is evaluated and checked to see if it is on the WGS-72 datum. Several charts will be exhibited and explained from a cartographic

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APPLICATIONS OF THE DoD WORLD GEODETIC SYSTEM - 1972 TO CHARTING BY THE USE OF A SEMI-AUTOMATED SYSTEM

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BIOGRAPHICAL SKETCH

Donald Wirak has a B.S. degree in Geography from the University of Maryland. In his work at the U.S. Navy Oceanographic Office he worked with computer applications for graticules, point plots, and electronic navigation systems. He has participated in ocean surveys and has extensive experience in compilation of nautical charts. He is now a senior cartographer in the Hydrographic Contract Branch of the Defense Mapping Agency Hydrographic/Topographic Center (DMAHTC) and is responsible for inspecting hydrographic charts compiled and color separated by private contractors and other government agencies. As a Contracting Officer Representative, Mr. Wirak has managed and completed the compilation of six DMAHTC nautical charts along the Pacific Coast of Panama and the Panama Canal.

ABSTRACT

DMA has a semi-automated system that is used to evaluate the horizontal datum of maps and charts for geodetic accuracy. Geodetic control descriptions in the DMAHTC library of holdings are used to make this evaluation. The computer system gives geodetic shifts to source maps, surveys, and charts. The chart is compiled from a panel base with the WGS-72 shifts applied. The final color proof of the chart is evaluated and checked to confirm that it is on the WGS-72 datum. Several charts will be exhibited and explained from a cartographic point of view as to how they were placed on WGS-72 datum. The exhibited charts are new charts of the Panama Canal and the Pacific coast of Panama. Examples of how the program was used to improve the geodetic accuracy of the charts on the last stage of compilation will be exhibited.

INTRODUCTION

With the advent of the Navy Navigation Satellite (NAVSAT) System and the ability of a ship using this system to determine its position within a tenth of a nautical mile, the need to produce nautical charts using a world wide datum became apparent to the Defense Mapping Agency (DMA). As a result, since 1975 the DMA has been producing charts whenever feasible on the World Geodetic System - 1972. This has been done using a digitizer interfaced with a programmable calculator and a control point data bank maintained by offline mini-computer. A programmable calculator gives evaluations of a chart or map geodetic accuracy based on the deviation between each pair of scaled identifiable charted control point and the compatible listed geodetic control point. By way of example, this small system was used to place a series of nautical charts along the Pacific coast of Panama on the World Geodetic System-1972. The system computed a shift from North American 1927 datum to WGS-72 datum for topographic maps and hydrographic charts and surveys. It was also used to evaluate the final color proofs of the seven charts and to further improve the geodetic accuracy of one chart of the series. This system has been improved and the concept has been applied by other mapping agencies in the United States government. It is presented here to show the practicability of the conversion to WGS-72 as well as to emphasize that smaller, less costly and earlier vintage computers can be used to convert charts and maps from most regional and many

HARDWARE CONFIGURATION

A data bank of geodetic control points is maintained on a Wang 2200 mini-computer with 32 K bytes of memory and a small disk drive that uses a removable 5 megabyte disk. When needed, the control points that fall within an area delineated by specified geographic coordinates can be printed out. The Wang 2200 is also programmed to perform datum shifts to WGS-72. The other part of the system is an off-line Wang 720 C programmable calculator with a cassette tape drive that is interfaced to an Altek Digitizer with a crosshair cursor. This part of the system is used to evaluate maps and charts for geodetic datum and accuracy.

HORIZONTAL EVALUATING PROCEDURE

The first step in the evaluation of a map or chart is to enter the geographic limits of the map or chart to be analyzed into the retrieval program on the WANG 2200. A printout of all geodetic control that falls within the geographic limits is printed out from a data bank of control points. If the data bank is lacking control points in the area, the DMAHTC geodetic library of holdings is searched for horizontal control point descriptions. If control is located, it is added to the data bank. In this way the size of the data bank has grown to approximately 15,000 control points.

When control is available, a frame of reference (geographic limits) is chosen for digitizing on the Altek digitizer. Types of projections (i.e. Mercator, Transverse Mercator, etc.) are not taken into consideration; therefore, to minimize distortion in the cases of smaller scale maps and charts where the distortion of distance and scale is obvious, smaller areas squared off by parallels and meridians which encompass one or more control points are used as a frame of reference for digitizing map features. The small area is embraced by a reduced band of latitude and band of longitude that allows the geographic positions to be interpolated more accurately. Large scale maps or charts are used in their entirety by entering the lower left (LL), lower right (LR) and upper left (UL) corners of the whole chart or map area.

With the LL, LR, and UL corners of the frame of reference (geographic limits) determined the following is done:

1. The chart number, edition, year, scale, datum and ellipsoid are keyed into the Wang 720 C.

2. The geographic positions of the LL, LR and UL corners or the frame of reference are keyed in and the delta latitude and delta longitude are entered.

3. The map or chart to be evaluated is taped in alignment with the x and y axis of the Altek Digitizer.

4. The LL, LR and UL corners of the frame of reference are digitized by placing the crosshair cursor over them.

5. The identifiable charted control point to be compared with the compatible listed geodetic control point is digitized.

6. The geographic position of the compatible geodetic control point is entered.

Steps #5 and #6 are repeated for each chart or map feature to be compared with a corresponding geodetic control point.

7. Errors are rejected (key-in error, wrong feature picked, etc.) and points are redigitized if necessary.

After the identifiable charted control point is digitized (steps #5 and #6) by placing the cursor over the point and then keying in the matching control point's geographic position: the Wang 720 interpolates the digitized feature into a geographic position. The delta phi and delta lamda between the digitized point and DMAHTC control point are computed and the delta North-South and delta East-West distance on the Earth's surface are computed and divided by the chart scale resulting in the North-South deviation and the East-West deviation in inches. The differences (digitized feature minus the control point position) in both latitude and longitude are each independently categorized (given a rating of 1, 2, 3 or 4). After the deviations between the features and control points are categorized, a category for the total number of points is given. If 90% of the North-South and East-West deviations are within:

.02" a category of 1 is given
.04" a category of 2 is given
.08" a category of 3 is given
For category 4 less than 90% of the points are within .08".

Charts and maps in the 1 and 2 categories are considered acceptable and on the datum of the compared control points.

If the category is 3 or 4 and if a chart could possibly be on a datum other than that of the geodetic control points, the program tests to determine whether or not a shift can be applied to the parallels and meridians of the map or chart that would bring the calculated deviations to a category of 1 or 2. If this is possible, a shift is computed for latitude and longitude in seconds and in inches to place the source on the same datum of the control points. If the systematic difference can not be found which results in category 1 or 2 a message of "inconsistent deviations" is printed and no shift is furnished.

It has been found by experience that attempts to shift charts with inconsistent deviations to plotted control points distorts the land detail and hydrography. The attempt to use individual plotted control points altered recommended tracks, lights in line, relative light positions and light sectors. These problems could be the result of incorrect control points, incorrectly plotted control points on the chart or incorrect geodetic control of the chart (some of the nautical charts that must be used are over 100 years old). However, charts with inconsistant deviations (if no hydrographic survey is available) can be positioned and used by matching with shoreline that is on the correct datum. On the new Panama chart series this matching of shoreline was used to fill in areas not covered by available hydrographic surveys.

ADVANTAGES AND LIMITATIONS OF EVALUATING PROCEDURE

The evaluation procedure depends entirely on the accuracy and description of control points furnished and can only apply comparisons based on the datum of the control points. This dependency makes it possible to evaluate charts or maps with any control of any datum, even WGS-72 control points. Control points determined by Geoceivers or other Doppler receivers could be used for a basis of evaluation and source could be shifted to WGS-72 without the use of any other program. However, in the case of the seven Panama charts a datum transformation program was used to shift source maps, charts and hydrographic surveys to WGS-72 due to the lack of control points determined by Geoceivers.

DATUM TRANSFORMATION

After the horizontal evaluation procedure is finished and no "inconsistent deviations" are determined, predetermined delta X,Y,Z, a and f are entered into the Wang 2200 computer. The geographic position of the center of the chart or map is entered (the program shifts points). The semi-major and semi-minor axes of the ellipsoid of the datum to be shifted to WGS 72 are called from the Wang 2200 program also. For this series of seven charts along the Pacific Ocean the following values of delta X, Y and Z computed in 1979 for Central America and delta a and delta f were used for the datum transformation from North American Datum 1927 to World Geodetic System 1972:

delta X	Shifts computed in 1979 between	-19 meters
delta Y	ellipsoid centers of	159 meters
delta Z	WGS 72 and Clarke 1866	182 meters
delta a	The difference between the semi-major axis of the WGS 72 ellipsoid and the Clarke 1866 ellipsoid	-71.4 meters
delta f	The difference between the flattening of the WGS-72 ellipsoid and the Clarke 1866 ellipsoid	-3.729585×10^{-5}

The abridged Molodensky formulas are used to perform the datum transformations (see Appendix).

The shift necessary for the datum transformation is printed out in the form of a special graticule shift note, which states that the shift is to be used for compilation only. The note <u>always</u> refers to the shifting of the parallels north or south in seconds and in inches and the shifting of the meridians east or west in seconds and in inches, to be applied to the evaluated map or chart. After the parallels and meridians are shifted according to the note the positions of any features on the map or chart are, for all practicable purposes, considered to be WGS-72 coordinates.

The last stage of the datum transformation is to evaluate the horizontal accuracy of the final proof of a new chart on the Wang 720 C by comparing the control points shifted to WGS-72. This last stage checks to determine if all of the source maps and charts were successfully shifted and paneled to WGS-72. Also this process shows up important geodetic control points such as navigational lights, monuments and hilltops that may have been drafted slightly off from the paneled base. All of the final proofs of the seven chart series of the Pacific coast of Panama were evaluated and resulted in horizontal evaluations of 1 and 2 which means that the charts were sucessfully compiled on WGS-72. After the WGS-72 evaluation a "note to the navigator" is printed which gives instructions for adding or subtracting values in seconds to or from the latitude and longitude of a given geographic position on the regional or local datum to make the geographic position plot correctly on the new WGS-72 chart.

ADVANTAGES AND LIMITATIONS OF DATUM TRANSFORMATION

The datum transformation is dependent on the datum shift constants developed by the Defense Mapping Agency. The Datum shift constants are available for virtually all regional datums such as NAD 27, SAD 69, European Datum as well as for many local datums. The datum shift constants are periodically updated and improved. These periodic updates and improvements

However, since the transformation is based only on mathematical formulas, the chart or map shifted should be evaluated for its horizontal accuracy before being shifted to WGS-72 datum. The shift in itself does not improve the inaccuracies that may be on the chart or map. In the case of the seven Panama charts most of the topographic sources and hydrographic surveys were accurately based on North American Datum 1927. The sources were shifted to WGS-72 datum or adjusted to match sources that could be shifted to WGS-72.

APPLYING WGS-72 SHIFT

The most direct use of the WGS-72 program was the evaluation of the E762 series of U. S. Army Map Service maps compiled in the early sixties from aerial photographs. Since the maps had evaluations of 1 and 2, the map evaluations were acceptable and proved to be on North American Datum 1927. Datum shifts were computed using the delta X, Y, and Z computed in 1979 for Central America and delta a and delta f between the Clarke 1866 ellipsoid and WGS-72 ellipsoid. The topographic source for chart 21584 with the shift applied to the maps were traced directly on the manuscript for 21584 which was the same scale of 1:50,000 as the topographic source. The hydrographic surveys of 1977 and 1978 had a computed shift based on survey control records at the U. S. Navy Oceanographic Office at Bay St. Louis. The final color proof for 21584 1:50,000 scale had an evaluation of 2 which means that 90% of all deviations of control points digitized fell within .04 of an inch on the chart and within 167 feet on the Earth's surface. The chart 21581 had no control points on the final color proof, so it could not be evaluated even though it was complied on WGS-72 Datum. The topo source that was shifted to WGS-72 covered more land area which included control points. This example shows one of the advantages of computing a general shift for each source chart, survey and map used to compile a nautical chart. In addition to being able to furnish a shift to charts with small areas with no control, the general shift averages out slight drafting errors of the source charts and maps.

THE USE OF COMMON SHIFTS

For the three smaller charts 21580, 21601 and 21605 it was discovered that a common shift could be used for all topography maps, and hydrographic surveys used for compilation. In case of the smaller scale chart 21605 a common shift was used for each type of source. However all items of the source were first evaluated to see if general shifts could be used to place all source on WGS-72 Datum. As a result the 15 sheet U. S. Army Map Service series E762 had the parallels shifted 4.2 seconds south and the meridians needed no shift. The same shift was also applied to the five regional 1:250,000 scale Panamanian maps. The 33 hydrographic surveys smooth sheets were evaluated and the shifts averaged out 4.3 seconds south for the parallels with no shift for the meridians. As one can see from these examples the source materials which are on North American Datum 1927 are very consistent as far as geodetic shifts are concerned. On the eastern portion of 21605 the old editions of DMAHTC charts 21600 and 21605 had to be used for hydrography. These two charts had the poorest evaluation of four with inconsistent deviations which means that no accurate geodetic shift was possible. Instead the charts were positioned by matching shoreline with the AMS and Panamanian regional maps. Most of the topo maps and hydrographic surveys were within +.2 seconds of the common shift used. Most of the new source was on North American Datum 1927. The common shift of all the sources produced a final proof of 21605 1:200,000 scale that had a "1", the best evaluation for WGS-72 Datum, which means that 90% of all deviations are within .02" on the chart and 333 feet on the Earth's surface. In this case the use of a common shift for many sources worked well. Similar procedures were used and similar results occurred with the other small scale charts 21580 and 21601.

CHART IMPROVEMENT

The examples of paneling 21581, 21584 and 21605 are straightforward examples of applying a geodetic shift to cartographic source material. Chart 21603 was paneled in the same manner as the other charts in the series, but in this case it was difficult to evaluate the final color proof. Several control points were off and others were not shown. When the geodesist checked with the cartographer, it was found that the points that were off were positioned by distances and bearings from the old edition of 21603 which had an evaluation of "4" with inconsistent deviations. The missing control points were not picked up from the panel base during the compilation. To correct this, the panel base was placed precisely under the translucent color proof and the missing control points were traced in the exact position as found on the panel base. These control points were Perico Island, Flamenco Island, Ancon Hill and Sosa Hill. The only station on the color proof was Taboga Island. The trig station descriptions consulted gave elevations for Sosa Hill and Ancon Hill which further improved the final color proof. The topo maps had the elevations of these important landmarks omitted. With these control points placed on the final proof, the chart was evaluated as 2 which is acceptable and considered on WGS-72 datum.

An auxiliary point evaluation was made of two lights taken from the old edition of 21603 and placed by distances and bearings on to the new 21603 chart. The previous edition chart had an evaluation of 4 with inconsistent deviations resulting in two misplaced lights. One light was almost a tenth of an inch off position. The lights and two other landmarks were replotted on the final proof using the exact WGS-72 geographic position. With these two evaluations, important landmarks were shown and two major navigational lights were positioned precisely. In this way the WGS-1972 system improved chart 21603.

CONCLUSION

The small semi-automated system has been used for six years and has been duplicated in other agencies in the United States government. The system can be programmed using a small computer interfaced with a datagrid or a digitizer. Charts and maps can be checked against existing geodetic control stations for horizontal accuracy. The evaluation procedure can be written to suit the requirements of a specific mapping project. The basis for evaluation can be made more critical for topographic projects. The technique described here offers a viable, economic, practical interim method for placing maps and charts on WGS-72. However, this technique is only as accurate as the control points used for evaluation and compilation. To achieve the accuracy associated with WGS-72, survey updates with Doppler Receivers are required to improve the control and datum shifts.

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COORDINATE TRANSFORMATION FORMULAS

GEODETIC DATUM TO WGS 72

A. The Standard Molodensky Formulas

$$\Delta\phi'' = \{-\Delta X \sin\phi \cos\lambda - \Delta Y \sin\phi \sin\lambda + \Delta Z \cos\phi$$
$$+ \Delta a (R_N e^2 \sin\phi \cos\phi)/a$$
$$+ \Delta f [R_M(a/b) + R_N(b/a)] \sin\phi \cos\phi\} \cdot [(R_M + H) \sin 1'']^{-1}$$

$$\Delta\lambda'' = [-\Delta X \sin\lambda + \Delta Y \cos\lambda] \cdot [(R_N + H) \cos\phi \sin 1'']^{-1}$$

$$\Delta H = \Delta X \cos\phi \cos\lambda + \Delta Y \cos\phi \sin\lambda + \Delta Z \sin\phi$$
$$-\Delta a (a/R_N) + \Delta f (b/a) R_N \sin^2\phi$$

B. The Abridged Molodensky Formulas

$$\Delta\phi'' = [-\Delta X \sin\phi \cos\lambda - \Delta Y \sin\phi \sin\lambda + \Delta Z \cos\phi$$
$$+ (a\Delta f + f\Delta a) \sin 2\phi] \cdot [R_M \sin 1'']^{-1}$$

$$\Delta\lambda'' = [-\Delta X \sin\lambda + \Delta Y \cos\lambda] \cdot [R_N \cos\phi \sin 1'']^{-1}$$

$$\Delta H = \Delta X \cos\phi \cos\lambda + \Delta Y \cos\phi \sin\lambda + \Delta Z \sin\phi$$
$$+ (a\Delta f + f\Delta a) \sin^2\phi - \Delta a$$

C. Definition of Terms in the Molodensky Formulas

ϕ, λ, H = geodetic coordinates (old ellipsoid)

ϕ = geodetic latitude. The angle between the earth's equatorial plane and the ellipsoid normal at a point (measured positive north from the equator, negative south)

λ = geodetic longitude. The angle between the plane of the Greenwich meridian and the plane of the geodetic meridian of the point (measured in the plane of the equator, positive east from Greenwich).

H = the distance of a point from the ellipsoid measured along the ellipsoidal normal through the point.

H = N + *h

*In [illegible]cates pa[illegible] meters which do not appear in the Abridged Molodensky

N = geoid-ellipsoid separation. The distance of the geoid above (+N) or below (-N) the ellipsoid.

*h = distance of a point from the geoid (elevation above or below mean sea level).

$\Delta\phi, \Delta\lambda, \Delta H$ = corrections to transform the geodetic coordinates from the old datum to WGS.

$\Delta X, \Delta Y, \Delta Z$ = shifts between ellipsoid centers of the old datum and WGS.

a = semimajor axis of the old ellipsoid.

*b = semiminor axis of the old ellipsoid.

*$b/a = 1 - f$

f = flattening of the old ellipsoid.

$\Delta a, \Delta f$ = differences between the parameters of the old ellipsoid and the WGS ellipsoid (WGS minus old).

e = eccentricity.

$e^2 = 2f - f^2$

R_N = radius of curvature in the prime vertical.

** $R_N = a/(1-e^2 \sin^2 \phi)^{1/2}$

R_M = radius of curvature in the meridian.

** $R_M = a(1-e^2)/(1-e^2 \sin^2 \phi)^{3/2}$

NOTE: All Δ-quantities are formed by subtracting old ellipsoid values from WGS ellipsoid values.

*Indicates parameters which do not appear in the Abridged Molodensky Formulas.

**For desk calculator computations involving commonly used ellipsoids, these values are given in Latitude Function Tables, i.e., Latitude Functions Clarke 1866 Spheriod, AMS TM No. 68, 1957.

WGS 72 Ellipsoid

Geodetic and Geophysical Parameters

Parameters	Notation	Magnitude	Standard Error (68.27%)
Gravitational Constant*	GM	$398600.5 km^3/sec^2$	±0.4
Second Degree Zonal*	$\bar{C}_{2,0}$	-484.1605×10^{-6}	--
Angular Velocity*	ω	$0.7292115147 \times 10^{-4}$ rad/sec	$\pm 0.1 \times 10^{-13}$
Semimajor Axis*	a	6378135 meters	±5
Flattening	f	1/298.26	$\pm 0.6 \times 10^{-7}$
Equatorial Gravity (Absolute System)	γ_e	978033.26 mgal	±1.8
Gravitational Constant (Mass of Earth's Atmosphere Included)	GM'	$398600.8 km^3/sec^2$	±0.4

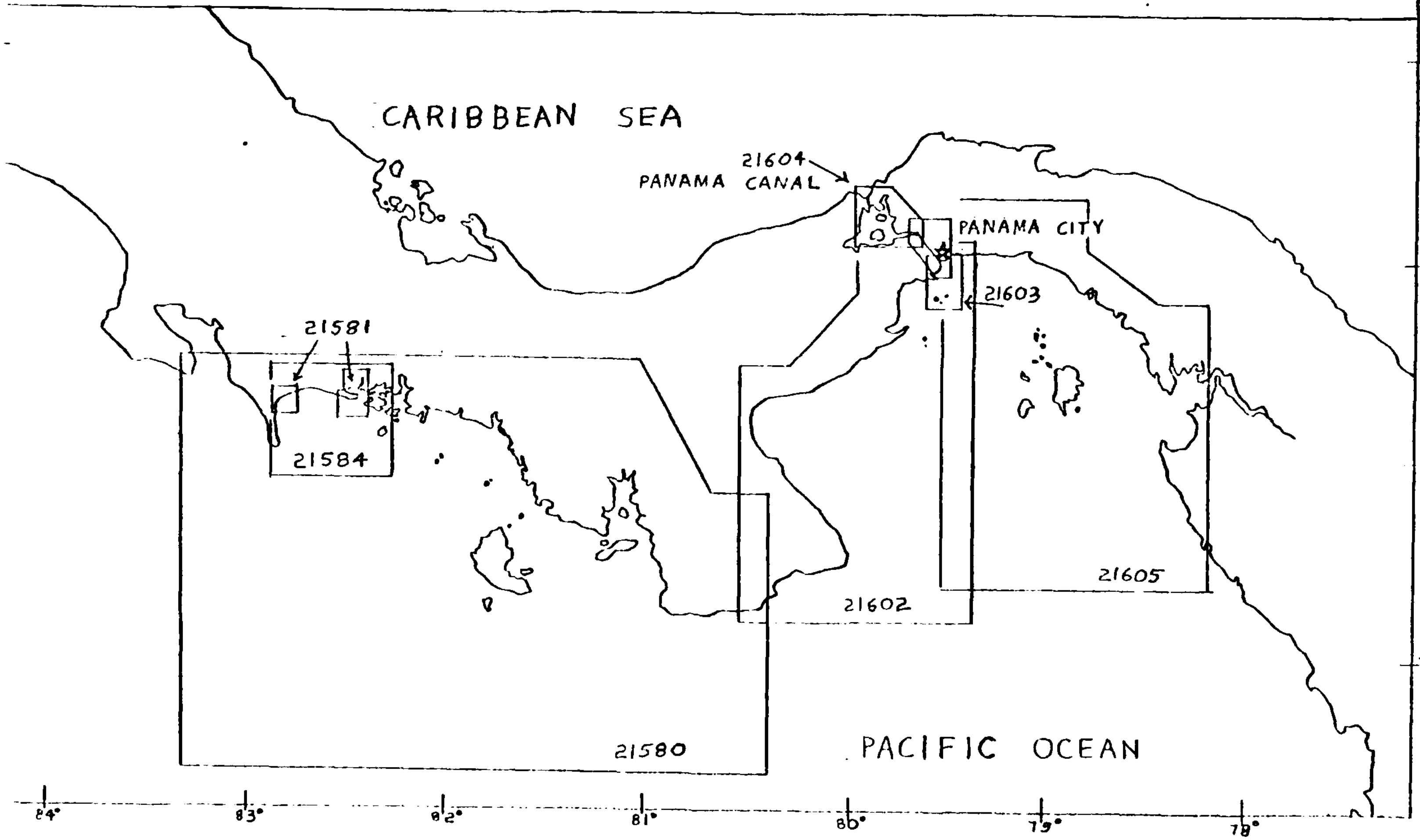
*The defining parameters of the WGS 72 Ellipsoid.

WGS 72 Ellipsoid

Associated Constants

Constants	Notation	Formula	Value
Semiminor Axis	b	$b = a(1-f)$	6,356,750.5 m
Major Eccentricity	e	$e = [f(2-f)]^{1/2}$	0.08181881066
Major Eccentricity Squared	e^2	$e^2 = f(2-f)$	0.006694317778
Minor Eccentricity	e'	$e' = e/(1-f)$	0.08209405392
Axis Ratio	b/a	$b/a = 1-f$	0.9966472205
Radius of Sphere with Equal Area	R_A		6,371,005.2 m
Radius of Sphere with Equal Volume	R_V		6,370,998.9 m
Ellipsoid Potential	U_o		6,263,688 kgal m
Mean Value of Normal Gravity	$\bar{G}_{Potsdam}$		979,772.87 mgal
Mean Value of Normal Gravity	[illegible]		979,758.87 mgal

DMA CHART SERIES - PACIFIC COAST OF PANAMA - PRINTED 1981



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